WHAT IS CLAIMED IS:

1. In an overall method of operating a system in which a boring tool is moved through the ground in a region which includes an electrical conductivity characteristic, said system including an above ground arrangement for tracking the position of and/or guiding the boring tool as the boring tool moves through the ground, said system being configured for transmitting a locating signal between the boring tool and said arrangement in said region, the improvement comprising the steps of:

compensating for skin depth error by measuring said locating signal such that measurements of the locating signal include skin depth error introduced as a result of said electrical conductivity characteristic and, thereafter, using said measurements in a way which determines a skin depth corrected position of the boring tool.

2. The improvement of Claim 1 wherein said measurements are produced by (i) transmitting the locating signal from the boring tool to said arrangement at a preselected number of different frequencies such that each frequency penetrates said region with a different skin depth, and (ii) measuring the intensity of the locating signal at each frequency to provide a number of intensity measurements corresponding to the preselected number of said different frequencies, and wherein the skin depth corrected position of the boring tool is determined by using said intensity measurements in combination.

3. The improvement of Claim 2 wherein four preselected frequencies are used.

4. The improvement of Claim 3 wherein the preselected frequencies are in the range of 2 to 40 kHz.

5. The improvement of Claim 2 wherein said intensity measurements are combined to extrapolate a zero frequency magnetic intensity for a particular set of said intensity measurements and, thereafter, the zero frequency magnetic intensity is used to determine the position of the boring tool relative to said arrangement.

6. The improvement of Claim 2 wherein determining the position of the boring tool using said intensity measurements includes the steps of (i) developing a set of magnetic intensity equations such that one equation corresponds to each frequency for use with one of the intensity measurements, said equations including a number of coefficients in frequency equal to the number of intensity measurements such that one of the coefficients is a constant which represents a steady state electromagnetic value of the locating signal, (ii) solving for said coefficients including the constant coefficient and (iii) using said constant coefficient as an electromagnetic reading at zero frequency to determine the position of the boring tool relative to said arrangement at zero frequency such the effect of skin depth is substantially reduced.

7. The improvement of Claim 6 wherein four of said frequencies are used and wherein said magnetic intensity equations are in the form:

$$
\begin{aligned}
S_1 &= S_0 + af_1^{0.5} + bf_1 + cf_1^{1.5} \\
S_2 &= S_0 + af_2^{0.5} + bf_2 + cf_2^{1.5} \\
S_3 &= S_0 + af_3^{0.5} + bf_3 + cf_3^{1.5} \\
S_4 &= S_0 + af_4^{0.5} + bf_4 + cf_4^{1.5}
\end{aligned}
$$

where S_0 is said constant coefficient, a, b, and c are the remaining coefficients and S_1-S_4 are the intensity measurements corresponding to preselected frequencies f_1-f_4.

8. The improvement of Claim 1 wherein certain ones of said measurements are used to determine a value for skin depth to be used during drilling, these certain measurements being obtained in a calibration procedure by transmitting the locating signal from the boring tool to said arrangement prior to drilling.

9. The improvement of Claim 8 wherein said calibration procedure is performed with the boring tool above ground.

10. The improvement of Claim 8 wherein said locating signal is transmitted at one fixed frequency.

11. The improvement of Claim 8 wherein said arrangement includes a portable walkover detector for use in locating said boring tool by (i) using the walkover detector to generate electromagnetic data which identifies an overhead position on the surface of the ground that is directly above said boring tool in a way which is not subject to skin depth error, (ii) measuring the overhead signal strength of the locating signal transmitted from the boring tool and (iii) using the overhead signal strength in conjunction with the determined value of the skin depth to determine the depth of the boring tool below the identified overhead position on the surface of the ground such that the depth of the boring tool is established based at least in part on said skin depth.

12. The improvement of Claim 11 wherein said depth of the boring tool along with the signal strength of the locating signal are established by successive approximation using the expression:

$$D = \left(\frac{m}{B_x} G\left(\frac{D}{\delta} \right) \right)^{\frac{1}{3}}$$

where D is the depth of the boring tool, m is the signal strength of said locating signal, B_x is the signal strength of the locating signal as measured by the walkover detector at said overhead position, δ is skin depth, and G is a function representing deviation of magnetic measurements in a conductive region.

13. The improvement of Claim 12 wherein magnetic measurements in a non-conductive region are consistent with a cubic law and wherein the function G represents deviation of magnetic measurements from the cubic law in a conductive region in terms of D/δ.

14. The improvement of Claim 12 wherein the expression $0 <= D/\delta < 3$ is satisfied.

15. The improvement of Claim 8 wherein the boring tool moves through the ground along an intended path while transmitting the locating signal and moves in an orientation which includes pitch, said boring tool including pitch sensing means and said locating signal exhibiting a field defined forward point at the surface of the ground with the boring tool at a particular point along the intended path, said field defined forward point being vertically above an inground forward point on said intended path through which said boring tool is likely to pass and wherein said arrangement includes a portable walkover detector, the boring tool being located by (i) using the walkover detector to generate electromagnetic data which identifies said forward point, (ii) measuring the signal strength of the locating signal at said forward point, as transmitted from the boring tool at said particular point and (iii) using the measured signal strength of the locating signal at said forward point in conjunction with said determined value of the skin depth and a sensed pitch value, determining the depth of the boring tool at said particular point and a forward distance on said intended path from the particular point at which the boring tool is located to said forward inground point based at least in part on said skin depth such that the location of the boring tool is established along said intended path.

16. The improvement of Claim 15 wherein the depth of the boring tool at said particular point and said forward distance are determined by solving the group of equations including:

$$B_\xi = B_\xi\left(\xi, \eta, \frac{r}{\delta}\right)$$
$$B_\eta = B_\eta\left(\xi, \eta, \frac{r}{\delta}\right)$$
$$\tan\gamma = \frac{B_\xi}{B_\eta}$$
$$D = r\sin(\lambda + \gamma)$$
$$B_y = \sqrt{B_\xi^{\,2} + B_\eta^{\,2}}$$
$$\tan\lambda = \frac{\xi}{\eta}$$
$$r^2 = \xi^2 + \eta^2$$

where the locating signal is symmetric with respect to a dipole axis and where D is the depth of the boring tool, r is the distance between the forward point and the boring tool, ξ is a projected distance of r onto the dipole axis of the boring tool, η, is a projected distance of r onto an axis which is perpendicular to the dipole axis, λ is an angle between r and the dipole axis, B_ξ is a component of locating signal intensity parallel to the dipole axis, B_η is a radial component of locating signal intensity parallel to the normal of the dipole axis, γ is measured pitch of the boring tool, B is the overall intensity of the locating signal and δ is the measured skin depth.

17. In an overall process in which a boring tool is moved through the ground within a region along an intended path while transmitting a locating signal, said region including an electrical conductivity characteristic and said locating signal exhibiting a field defined forward point which field defined forward point is vertically above an inground

forward point on said intended path through which said boring tool is likely to pass with the boring tool initially located at a particular point on the intended path, said system including an above ground arrangement for tracking the position of and/or guiding the boring tool as it moves through the ground using a locating signal that is transmitted from the boring tool to said arrangement such that the electrical conductivity of said region results in a skin depth which modifies penetration of the locating signal into said region and, consequently, which produces skin depth error when magnetic readings of the locating signal are used to determine the location of the boring tool relative to said arrangement under an assumption that said region is electrically non-conductive, a method of determining the depth of said boring tool at said particular point, said method comprising the steps of:

a) measuring the skin depth in said region in a predetermined way;

b) identifying said field defined forward point on or above the surface of the ground and identifying an overhead point on or above the surface of the ground and directly above the boring tool at said particular point;

c) measuring a forward distance defined at the surface of the ground between the overhead point and the forward point; and

d) using the forward distance, said skin depth and certain characteristics of said locating signal at said forward point, determining the depth of said boring tool at said particular point.

18. The method of Claim 17 wherein said locating signal includes a vertical and a horizontal component and wherein the locating signal includes the characteristic of its horizontal component being equal to zero at said forward point.

19. In an overall process in which a boring tool is moved through the ground within a region along an intended path while transmitting a locating signal, said region including an electrical conductivity characteristic and said locating signal exhibiting a field defined forward point which field defined forward point is vertically above an inground forward point on said intended path through which said boring tool is likely to pass with the boring tool initially located at a particular point on the intended path, said system including an above ground arrangement for tracking the position of and/or guiding the boring tool as it moves through the ground using a locating signal that is transmitted from the boring tool to said arrangement such that the electrical conductivity of said region results in a skin depth which modifies penetration of the locating signal into said region and, consequently, which produces skin depth error when magnetic readings of the locating signal are used to determine the location of the boring tool relative to said arrangement under an assumption that said region is electrically non-conductive, a method of determining the depth of the boring tool from any forward point along the intended path of the boring tool, said method comprising the steps of:

a) configuring the intended path in said region such that said forward point is at a higher elevation on the surface of the ground than said particular point;

b) establishing the actual depth of the boring tool at said particular point;

c) measuring a vertical elevation difference between the particular point and the forward point;

d) sensing the locating signal at said forward point while the boring tool is at said particular point to determine an uncorrected depth of the boring tool which is subject to skin depth error;

e) using the measured vertical elevation difference, the actual depth of the boring tool at said particular point and the uncorrected depth of the boring tool measured from the forward point, determining a forward point skin depth correction factor;

f) after having advanced the boring tool to a subsequent particular point on said intended path associated with a subsequent forward point, determining a corrected depth of the boring tool

i) measuring the locating signal at said subsequent forward point using said arrangement to produce electromagnetic data,

ii) determining the uncorrected depth of the boring tool at said subsequent particular point using the electromagnetic data such that the uncorrected depth at the subsequent particular point is subject to skin depth error, and

iii) multiplying the uncorrected depth at the subsequent particular point by said forward skin depth correction factor to determine depth of the boring tool at the subsequent particular point corrected for skin depth.

20. The method of Claim 19 wherein said skin depth correction factor is given by

$$\frac{D_{OH\delta} + \Delta z_G}{D_{FLP}}$$

where $D_{OH\delta}$ is the actual depth of the boring tool at said particular point, Δz_G is the elevation difference between the particular point and the forward point and D_{FP} is the uncorrected depth of the boring tool measured at said forward point.

21. A method of determining skin depth in a region of earth by using a dipole transmitter configured for transmitting a signal which exhibits a dipole field and a receiver configured for receiving said signal along at least one receiving axis, said method comprising the steps of:

a) positioning said dipole transmitter on the surface of the ground in said region;

b) transmitting the dipole signal from the dipole transmitter to said receiver in a predetermined way to produce electromagnetic data; and

c) using the electromagnetic data to determine the skin depth within region.

22. The method of Claim 21 wherein said dipole field includes a center axis and defines an orthogonal plane perpendicular to said center axis which bisects said dipole field, said step of positioning the dipole transmitter on the surface of the ground including the steps of orienting the dipole transmitter such that said center axis extends generally along the surface of the ground with an orthogonal axis in said orthogonal plane also extending generally along the surface of the ground and wherein the step of transmitting said dipole signal from the dipole transmitter to the dipole receiver includes the steps of (i) positioning the receiver on said orthogonal axis at a first offset distance from said center axis with said receiving axis substantially parallel to said center axis and measuring a first value of said dipole signal along said receiving axis, (ii) positioning the receiver on said orthogonal axis at a second offset distance from said center axis with said receiving axis substantially parallel to said center axis and measuring a second value of said dipole signal along said receiving axis, and (iii) using the first and second values of said dipole signal as said electromagnetic data.

23. The method of Claim 22 wherein the skin depth is determined using the expression:

$$\left(g_1 x_2^{\ 3} - g_2 x_1^{\ 3}\right)d\varepsilon^3 + \left(g_1 x_2^{\ 2} - g_2 x_1^{\ 2}\right)c\varepsilon^2 + \left(g_1 x_2 - g_2 x_1\right)b\varepsilon + g_1 - g_2 = 0$$

where δ is skin depth, ε is equal to $1/\delta$, B_{y1} is the first value of said dipole field measured at said first offset distance from the center axis and B_{y2} is the second value of said dipole field measured at said second offset distance from the center axis where the first and second offset distances are denoted as x_1 and x_2, respectively, and

$$g_1 = B_{y1} x_1^{\ 3},$$

$$g_2 = B_{y2} x_2^{\ 3}.$$

24. In a system in which a boring tool is moved through the ground in a region which includes an electrical conductivity characteristic, said system including an above ground arrangement for tracking the position of and/or guiding the boring tool as it moves through the ground using a locating signal that is transmitted between the boring tool and said above ground arrangement such that the electrical conductivity of said region results in a skin depth which modifies penetration of the locating signal into said region and, consequently, which produces skin depth error when magnetic readings of the locating signal are used to determine the location of the boring tool relative to said above ground arrangement under an assumption that said region is electrically non-conductive, the improvement comprising:

a compensation arrangement forming part of said boring tool and/or part of said above ground arrangement for compensating for skin depth error based on measurements of said locating signal such that a skin depth corrected position of the boring tool is established.

25. The improvement of Claim 24 wherein said compensation arrangement includes a calibration arrangement which is configured for determining the skin depth in said region using said locating signal in a predetermined way and said compensation arrangement further includes a processing arrangement which is configured for using the skin depth during a drilling operation to determine said skin depth corrected position of the boring tool.

26. The improvement of Claim 25 wherein said compensation arrangement forms part of the above ground arrangement.

27. The improvement of Claim 25 wherein said locating signal is transmitted at one frequency.

28. The improvement of Claim 27 wherein said boring tool includes a dipole transmitter configured for transmitting said locating signal such that the locating signal is in the form of a dipole field having a center axis and defining an orthogonal plane perpendicular to said center axis which bisects said dipole field and wherein the above ground arrangement is a portable detector which houses said compensation arrangement and which includes said

calibration arrangement and further includes a receiving axis along which said locating signal is detected, said calibration arrangement being configured for determining the skin depth using at least two measurements of said locating field which are obtained by positioning the dipole transmitter on the surface of the ground such that said center axis extends generally along the surface of the ground with an orthogonal axis in said orthogonal plane also extending generally along the surface of the ground and wherein the locating signal from the dipole transmitter is measured at first and second offset distances from said center axis to obtain said two measurements, each measurement being obtained with the portable detector placed on said orthogonal axis at said first and second offset distances, respectively, having the receiving axis of the portable detector oriented parallel to said center axis.

29. The improvement of Claim 24 wherein said compensation arrangement includes means forming part of said boring tool and part of said above ground arrangement for transmitting said locating signal through said region using at least two different frequencies for any particular location of the boring tool within said region and for receiving the locating signal at said different frequencies to generate measurements of the locating field at said different frequencies for use in determining said skin depth corrected position of the boring tool at any particular location within said region.

30. The improvement of Claim 29 wherein the effect of skin depth is determined by extrapolating a zero frequency magnetic intensity for a particular set of said intensity measurements and, thereafter, the zero frequency magnetic intensity is used to determine the particular location of the boring tool relative to said arrangement.

31. The improvement of Claim 30 wherein said compensation arrangement includes processing means forming part of said above ground arrangement configured for using a set of magnetic intensity equations in which each equation corresponds to one frequency for use with one of the intensity measurements, said equations including a number of coefficients equal in number to the number of intensity measurements such that one of the coefficients is a constant which represents a steady state electromagnetic value of the locating signal, said processing means being configured for solving for said coefficients including the constant coefficient and, thereafter, for using said constant coefficient as an electromagnetic reading to determine the particular location of the boring tool relative to said arrangement at zero frequency such the effect of skin depth is reduced.

32. The improvement of Claim 31 wherein four of said frequencies are used and wherein said magnetic intensity equations are in the form:

$$\begin{aligned}
S_1 &= S_0 + af_1^{0.5} + bf_1 + cf_1^{1.5} \\
S_2 &= S_0 + af_2^{0.5} + bf_2 + cf_2^{1.5} \\
S_3 &= S_0 + af_3^{0.5} + bf_3 + cf_3^{1.5} \\
S_4 &= S_0 + af_4^{0.5} + bf_4 + cf_4^{1.5}
\end{aligned}$$

where S_0 is said constant coefficient, a, b, and c are the remaining coefficients and S_1-S_4 are the intensity measurements corresponding to the plurality of frequencies f_1-f_4.

33. The improvement of Claim 29 wherein said boring tool includes transmitter means forming part of said compensation arrangement configured for transmitting said locating signal at said frequencies and wherein said above ground arrangement includes receiver means forming part of said compensation arrangement for receiving the locating signal at said frequencies.

34. The improvement of Claim 29 wherein transmitter means transmits said frequencies in an alternating manner such that one frequency at a time is transmitted.

35. The improvement of Claim 34 wherein said frequencies alternate at a rate which effectively causes all of the frequencies to be transmitted from any one location of the boring tool irrespective of movement of the boring tool caused by a drilling operation.

36. The improvement of Claim 34 wherein said frequencies alternate at a frequency at or above approximately 10 Hz.

37. The improvement of Claim 24 wherein said above ground arrangement includes a portable walkover detector configured for receiving said locating signal and said locating signal is transmitted from said boring tool.

38. The improvement of Claim 37 wherein said compensation arrangement includes means forming part of said boring tool and part of said portable walkover detector for transmitting said locating signal through said region using at least two frequencies for any particular location of the boring tool within said region and for receiving the locating signal at said frequencies to generate measurements of the locating field at said frequencies for use in determining said skin depth corrected position of the boring tool at any particular location within said region.

39. The improvement of Claim 24 wherein said locating signal is transmitted from said boring tool and wherein said above ground arrangement includes at least two detectors, each of which is configured for receiving said locating signal at a fixed location within said region to produce said measurements of the locating signal.

40. The improvement of Claim 39 wherein said compensation arrangement includes means forming part of said boring tool for transmitting said locating signal using at least two different frequencies and means forming part of said above ground detectors for receiving said frequencies for any particular location of the boring tool within said region for use in generating measurements of the locating field at said frequencies to determine said skin depth corrected position of the boring tool.

41. A drilling apparatus for performing underground boring in a region having an electrical conductivity which results in a skin depth that modifies penetration of electromagnetic signals into said region, said apparatus comprising:

a) a boring tool which is configured for moving through the ground including means for emitting a locating signal using at least two frequencies each of which is subject to said skin depth; and

b) an above ground arrangement configured for receiving said locating signal at said frequencies as the boring tool moves underground, the received frequencies being used in establishing a corrected position of the boring tool in a way which compensates for said skin depth.

42. The apparatus of Claim 41 wherein the effect of said skin depth is compensated for by configuring said above ground arrangement to extrapolate a zero frequency electromagnetic intensity for a particular set of said intensity measurements produced at substantially one particular location of the boring tool and, thereafter, using the zero frequency electromagnetic intensity to determine the particular location of the boring tool corrected for said skin depth.

43. The apparatus of Claim 42 wherein said above ground arrangement includes processing means for using a series of magnetic intensity equations in which each equation corresponds to one of said frequencies for use with one of the intensity measurements, said equations including a number of coefficients equal in number to the number of intensity measurements such that one of the coefficients is a constant which represents a steady state electromagnetic status of the locating signal, said processing means being configured for extrapolation by solving for said coefficients including the constant coefficient and, thereafter, using said constant coefficient as an electromagnetic reading to determine the particular location of the boring tool relative to said arrangement at zero frequency.

44. The improvement of Claim 43 wherein four of said frequencies are used and wherein said magnetic intensity equations are in the form:

$$
\begin{aligned}
S_1 &= S_0 + af_1^{0.5} + bf_1 + cf_1^{1.5} \\
S_2 &= S_0 + af_2^{0.5} + bf_2 + cf_2^{1.5} \\
S_3 &= S_0 + af_3^{0.5} + bf_3 + cf_3^{1.5} \\
S_4 &= S_0 + af_4^{0.5} + bf_4 + cf_4^{1.5}
\end{aligned}
$$

where S_0 is said constant coefficient, a, b, and c are the remaining coefficients and S_1-S_4 are the intensity measurements corresponding to the plurality of frequencies f_1-f_4.

45. The apparatus of Claim 41 wherein said locating signal is transmitted from the boring tool and said above ground arrangement includes a portable walkover detector configured for receiving said locating signal at said predetermined frequencies.

46. The apparatus of Claim 41 wherein said locating signal is transmitted from said boring tool and wherein said above ground arrangement includes at least two detectors, each of which is configured for receiving said locating signal at said frequencies in a fixed location within said region.

47. The apparatus of Claim 41 wherein four of said predetermined frequencies are used.